S1'-100 POWERPROGRAM

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Abstract

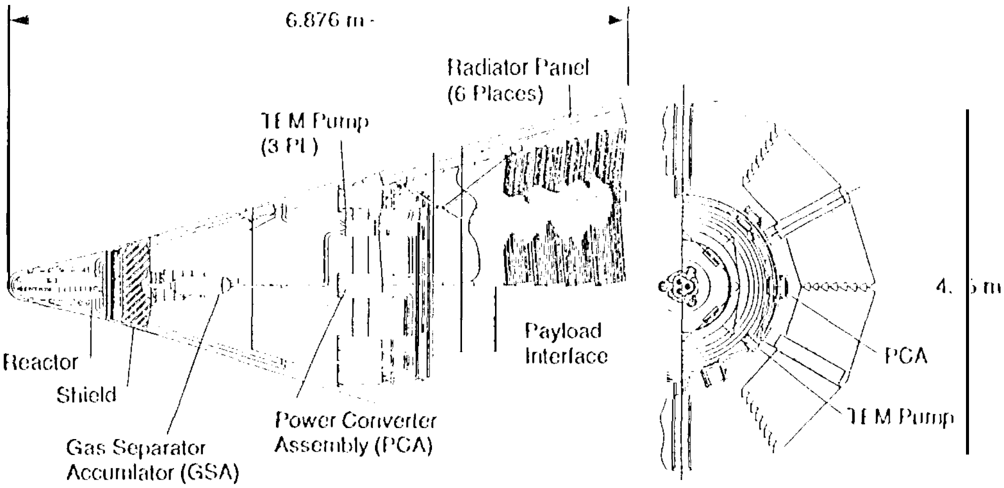
This paper presents a brief summary of the S1'- 100 project accomplishments and the tasks remaining to complete the space reactor power system development. A fast-track development approach was started in 1992 which would use near-term technology for early nuclear electric propulsion (NEP) planetary missions. In parallel, the 1CCIIIl0IIJ:% would be improved for the more aggressive NEP missions. A conceptual design for a twenty-kilowatt space reactor thermoelectric power system was completed using near-term technology. The SP-100 near-term technology is developed except for (1) the converter, (?) the pump, and (3) the control drive actuator (CDA). The first converter was fabricated in September 1993. A CDA subassembly was put on test at the end of September 1993. The critical bonding steps for assembling the TE cells and the pump ducts were developed by the end of September 1993. The remaining technology development tasks for the early systems are primarily building and testing a converter, a pump, and an actuator. The SP-100 technology is well documented and therefore available when the need for space reactor power systems returns.

INTRODUCTION

In March of 1983 the United States initiated the SP- 1001'1(1:,1:1111 to develop a space reactor power system capable of providing lo's to 100's" of kilowatts of electrical power to maintain national security against threats in the next century and to support new horizons in the exploration of space, both manned and unmanned. During the first three years of the program, system studies and critical feasibility issues were addressed to determine the lowest mass, ten-year life, and least cost space reactor power system to accomplish military and civilian missions. The result was the selection of a fast spectrum uranium nitride, lithium-cooled reactor coupled to thermoelectric energy conversion cells and heat pipe radiator panels to reject the waste heat to space. Since that time, considerable progress has been made in developing this space reactor power system. A recent conceptual design of a 20 kWe space reactor thermoelectric system is shown in Figure 1.

The S1'- 100 Program has essentially completed its component performance development phase. The critical technologies and fabrication techniques required to build a reactor space power system have been validated and components fabricated. This includes components for both the nuclear and space subsystems. The nuclear subsystems consist of the reactor, reactor instrumentation and control (I&C), and the shield subsystems. The space subsystems include the converter, heat transport, and heat rejection subsystems. Other activities completed under the S1'- 100 Program include the development of system requirements, a generic flight system (GFS) design, a detailed validation plan, a thaw design to permit multiple shutdown and restarts, procedures for qualification and acceptance testing, and several conceptual designs for a number of potential missions. Truscello and Rutger (1992) described the SP-100 Program and the hardware developed as of January 1992.

The reactor fuel, the multicell thermoelectric converter, materials data, the fabrication techniques and the components developed under the S1'- 1 00 Program are available to support future space programs which require safe, dependable, long-life, 10- to 300-kWe power sources.



Key System Parameters	
Net Power EOM 5 yr	20.6 kWe
Thermal Power EOM	596.0 kWe
Reactor Outlet Temp.	1375 K
Total Radiator Area	30.8 m^2
Power Converter Assembly	6
TEM Pumps	3

FIGURE 1. 20-kWe Space Reactor Thermoelectric System.

Applications for SP-100

Past studies have indicated that nuclear electric propulsion (NEP) using a 100-kilowatt electric (kWe) power system with a specific mass of 40 kilograms per kilowatt (kg/kW) and a lifetime of 10 years would enable the most aggressive planetary missions as described by Kelley and Yen (1992) in their AIAA paper. Since 1986, the SP-100 project has been developing technology that could meet these requirements. Very recent studies by Yen (1993) have identified attractive three-to-five-year missions employing NEP at lower power levels (20 to 40 kWe). These missions can be accomplished with SP-100 hardware based on today's SP-100 technology that results in greater system specific mass and shorter demonstrated system lifetime than required for the aggressive planetary missions. The configuration of an early 20 kWe NEP spacecraft is shown in Figure 2.

Further optimization, mass reduction, and demonstration of longer component lifetimes is required to support the aggressive outer planet missions previously mentioned. Studies have also recently indicated that manned missions to the lunar surface and to Mars would be enabled and performed at less cost with the use of space reactor power systems.

The early 20 to 40 kWe space reactor thermoelectric system could also be used for a manned lunar and/or Mars outpost. Besides its use on NASA missions, this early hardware would be suitable for a number of DOD and commercial applications such as military surveillance, high power communication, and air traffic control missions.

At this time, neither agency, NASA nor DOD, have endorsed funding a mission which would make use of the SP-100 reactor space power system technology. Evaluation of potential commercial applications for nuclear power is continuing. The Department of Defense has been evaluating a variety of nuclear power concepts for dual use power sources for both propulsion and electrical power. It is possible to directly adapt the SP-100 space reactor power system to provide a thermal propulsion capability. The components and materials technology developed by the SP-100 program is applicable for this DOD effort. Currently, NASA's plans do not include the use of reactor space power before the year 2000.

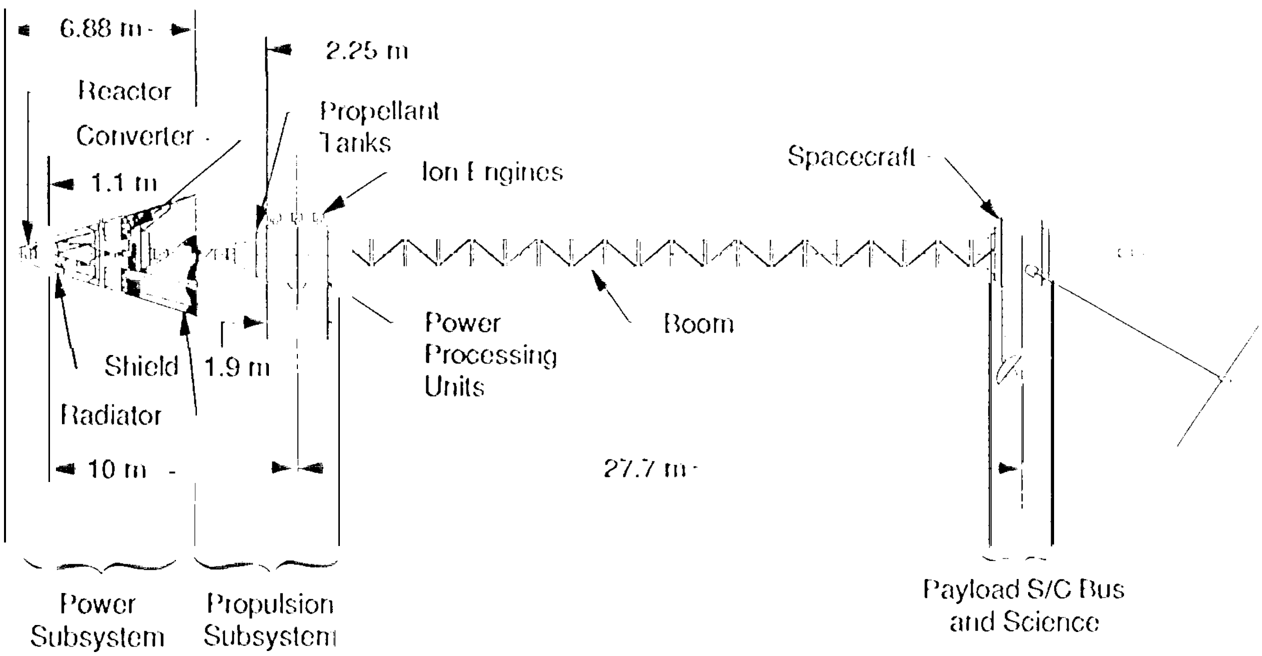


FIGURE 2. 20-kWe NEP Spacecraft (Side Thrust).

SP-100 Program Plans

To accommodate reduced funding during FY 93, the SP-100 program shifted its emphasis from ground demonstration of a complete power system to ground demonstration of the components. The components are developed, fabricated and tested to meet the requirements as defined for a near-term, intermediate and mature system. Most of the key components required for a space reactor power system were fabricated by the end of FY 93. So using the near-term technology as a base, the components for the intermediate and mature systems would be improved as illustrated by Figure 3. A summary of the technology differences between near-term, intermediate and mature SP-100 Reactor Thermoelectric systems is given in Table 1. Testing of the pump, converter, and actuator will be required in the future as well as accelerated component lifetime testing.

As no user agency has an identified mission for the SP-100 space reactor power system, the Department of Energy is planning to close out the SP-100 Space Reactor Power System program during FY 94. NASA has also discontinued its funding for the program in FY 1994. During closeout in FY 94, the Department of Energy will document the progress made in the SP-100 program so that the technology can be retrieved for future use.

Hardware Status and Remaining Tasks

Demonstration of suitable technology for early missions is essentially complete. Pluta et al. (1993) describe the latest hardware and test results in a paper published in the 1993 IECEC proceedings. During FY 93, three key SP-100 components (pump, converter, and actuator) were fabricated. Tasks that remain to be completed when the program is restarted at some future date include performance testing of components, component/system lifetime validation, and potentially an integrated electrically heated system test. The major components for the reactor, shield, and waste heat radiator were developed, fabricated, and tested prior to FY 93. Below is a summary of the most significant technical accomplishments through FY93 and the remaining tasks necessary to complete this SP-100 development program.

Nuclear Subsystems

The SP-100 nuclear subsystems technology, except for the control drive actuator, is ready for a near-term 10 to 40 kWe flight system design, development, fabrication and qualification. The nuclear subsystems are the reactor, reactor instrumentation and shield which are discussed below.

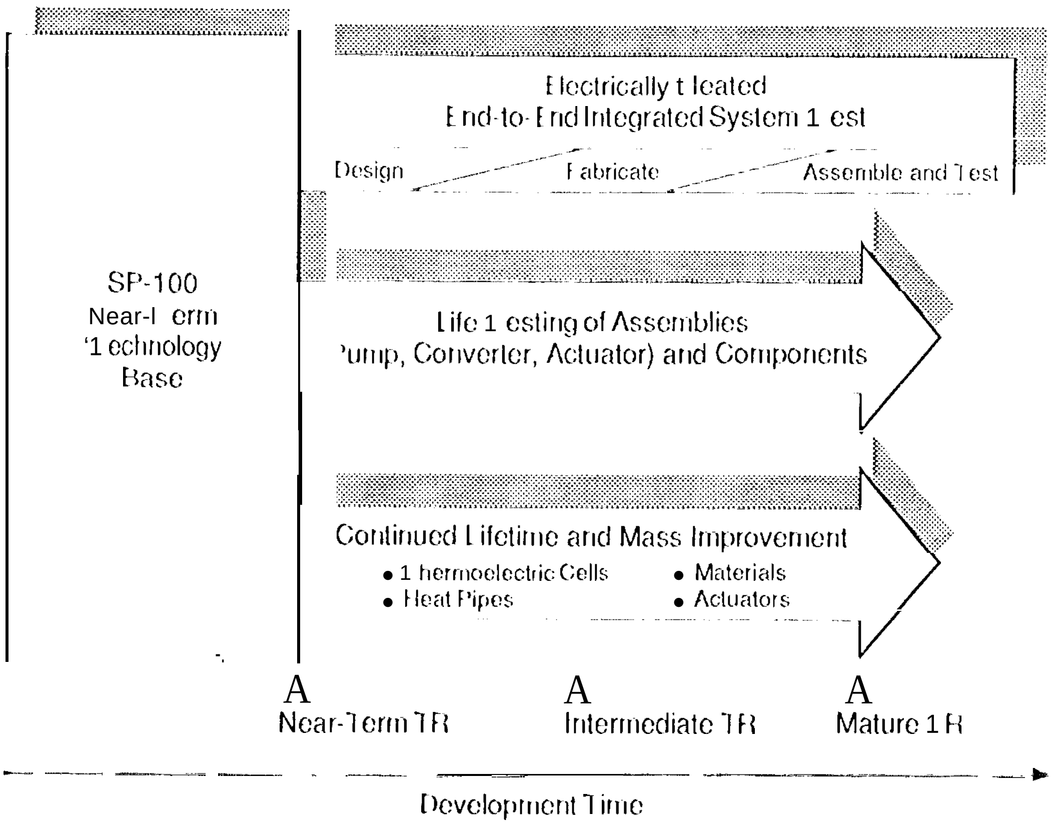


FIGURE 3. Fast-Track SRPS Development.

Safety Status

The safety analyses performed in support of the ground test preliminary safety analysis report (PSAR) provides confidence that the subsystems can be designed to meet all U. S. safety requirements. The 20-kWe SP-100 reactor and shield subsystem designs are shown in Figure 4. The reactor contains inherent safety features including a negative temperature reactivity coefficient. The reactor design includes highly reliable shutdown systems. This design has an independent core cooling system should the reactor require protection against the unlikely event of loss of reactor coolant in space. A high temperature reentry shield surrounds the reactor to assure that the reactor remains intact in case of an inadvertent reentry. The reactor has been designed to remain subcritical under all credible accident scenarios. The reactor is designed to be launched cold and will contain no fission products nor be radioactive during launch. The design has been subjected to several rigorous independent safety reviews with no negative findings.

Reactor Status

A comprehensive fuels and materials data base has been completed. The data base includes information on irradiation effects on niobium alloys and uranium nitride fuel pins that were irradiated to burnups greater than that required for a ten-year mission. This was accomplished by accelerated fuel testing to simulate the full power seven-year lifetime. There have been no fuel pin failures while operating at clad temperatures of 1500 K, 100 K hotter than the hottest fuel pin design temperature in the operational system. Cold critical testing was performed in the DOE zero power physics reactor (ZPPR) in Idaho to verify the neutronic design codes for operation, shutdown, and safety under simulated operational and accident conditions. Hydraulic tests were performed on reactor mockups to establish the core's fluid flow resistance and flow paths. A Generic Flight System (GFS) design of a reactor subsystem for a 100-kWe thermoelectric power system is available as a starting point for other flight space reactor power system designs.

All of the uranium nitride fuel pellets for a 100-kWe space reactor thermoelectric power system have been fabricated and are in storage at Los Alamos. Fabrication readiness reviews and approval have been completed for fabricating the

TABLE 1. SP-100 Reactor Thermoelectric Technology

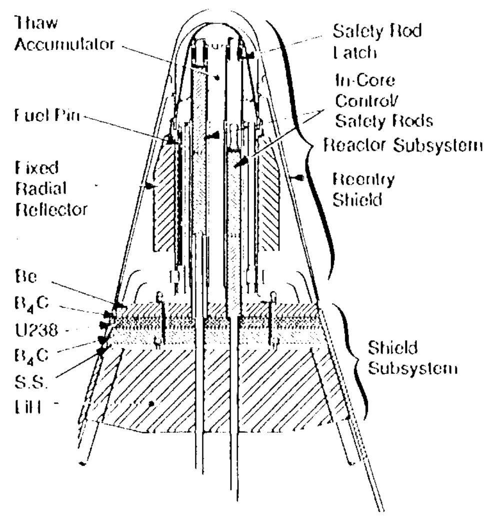
	Near-Term	Intermediate	Mature
System			
I'()\\'ei	10-40 kWe	10-60 kWe	10300" kWe
Lifetime (FullP/Mission)	3/5 Years	5/7 Years	7/10 Years
Reactor			
Fuel	UN	UN	UN
Coolant	Lithium	Lithium	1.ithium
Clad	Nb-1Zr/Re	PWC-11/Re	PWC-11/Re
Structure	Nb-1Zr	Nb-1Zr	PWC-11
Outlet Temperature	1350 K	13-15 K	1400 K
Reactor 1 &C			
Mode	Dual	Dual	Separate
Safety	111-('oil"	In-Reflector	111-('01("
Control	III-('OIL"	In-Reflector	Reflector
Heat Transport			
Pump	TEM	TEM	TEM
Material	Nb-1Zr/PWC-11	Nb-1Zr/PWC-11	PWC-11
TE Material	SiGe-0.67X10 3/K	SiGe(GaP)-0.72X10 3/K	SiGe(GaP)-0.85X 10 3/K
Converter			
Type	Multicell	Multicell	Multicell
I'()\\'cl	8.8 We/Cell	10.8 We/Cell	12.8 We/Cell
TE Material	SiGe-0.67X10 3/K	SiGe(GaP)-0.72X10-3/K	SiGe(GaP)-0.85X10-3/K
Radiator			
Heatpipe	K-Ti\2.5 cm Dia.	K-Nb 1Zr\2.5 cm Dia.	K-Ti\1.3 cm Dia
Fins	Ti	C-C	('-C
Armor	Ti	('-('	('-('
Duct	[illegible]	Nb1Zr	Ti

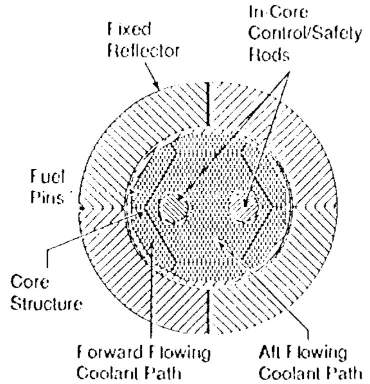
bonded cladding and the fuel pins. Assembly flow sheets have been prepared for fabricating the reactor. Fabrication development for the reactor subsystem components have been completed and technology readiness has been demon-strated.

Excellent progress was made in re-establishing and improving technology required to manufacture complex structures from niobium alloy materials. An extensive high temperature mechanical properties data base for recently manufactured niobium alloy materials (Nb-1 Zr and PWC-11) has been developed. Significant quantities of Nb-1 Zr and PWC-11 alloy tubing and piping have been produced by industrial vendors in accordance with SP-100 specifications. Manufacturing complex reactor components from Nb-1 Zr and PWC-11 has demonstrated technology readiness.

Remaining Reactor Tasks

The reactor subsystem technology development for the near-term subsystem is complete. To reduce mass and increase reactor life and reliability, the long life materials database needs to be completed. This includes additional long-term creep tests on PWC-11 material, fabrication process development and documentation for PWC-11 to retain its high creep strength, and additional or continued fuel pin irradiation and post-test examinations. Also, the reactor subsystem needs





Parameter	Value
Thermal power (kW)	596
Number of fuel pins	882
Fuel pellet diameter (mm)	6.4
Liner	Re
Fuel column height (cm)	30.7
Reactor vessel O.D. (cm)	30.8
Radial reflector thickness (cm)	8.1
Reactor vessel length (cm)	108
Number of in-core rods	Two
In core U-tubes	Two

FIGURE 4. Reactor and Shield Subsystems.

to be fabricated and tested in an end-to-end electrically heated system test. This latter task might well be done as part of a flight hardware development program.

Reactor I&C Status

Remaining Reactor I&C Tasks

The control/safety drive actuator subassembly, as shown in Figure 6, (motor/brake/clutch/ gears/spring drive/position sensor) was fabricated, installed, and performance testing initiated at the end of September 1993. The lifetime testing and evaluation in a thermal vacuum environment needs to be completed in a follow-on or new start program. The balance of the control/safety drive assembly (CDA) is developed, designed and needs to be fabricated and tested. The actuator subassembly and balance of the CDA need to be integrated and tested in a prototypic thermal vacuum environment and then continued on life test. An end-to-end system test controller needs to be designed and built as a breadboard controller for the system test.

Continued lifetime development and mass reduction of CDA components, multiplexers and sensors are required to demonstrate low mass and ten-year life. Life testing of CDA components, multiplexers and sensors remains to be done to validate long life, highly reliable reactor I&C subsystems for the intermediate and mature systems.

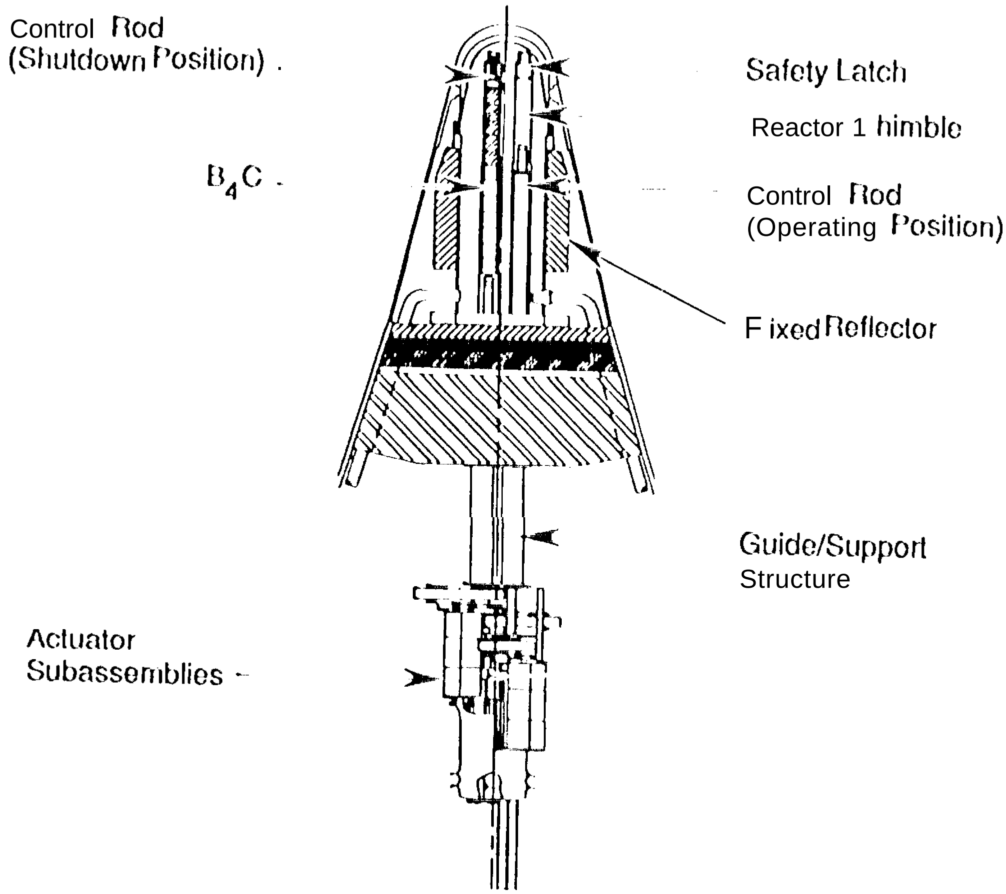


FIGURE 5. Reactor I&C Subsystem.

__Shield Status__

The shield subsystem technology development for a near-term system is complete. The shield subsystem, as shown in Figure 4, has been developed, designed, and the manufacturing plans are complete. Materials manufacturing processes are developed and compatibility characteristics of prototype materials within the shield have been demonstrated for ten-year life. The lithium hydride (LiH) gamma irradiation behavior at operating temperatures for ten years has been validated.

__Remaining Shield Tasks__

Completing the shield and material data base is required to reduce mass and increase reliability. Neutron irradiation of LiH at temperature is required to confirm that the LiH swelling behavior is the same as that for gamma irradiation. Also, the LiH thermal conductivity change, if any, due to irradiation needs to be determined. The shield subsystem needs to be fabricated and tested in an end-to end system test prior to flight.

__Space Subsystems__

The space subsystems are nearly developed, as discussed by Mondt (1991), for near-term, 10 to 40 kWe, three-to five-year systems. The type approval (TA) thermoelectric cells are fabricated and on test. The TA cells are being tested as individual cells and have been incorporated into a fabrication development pump and converter to demonstrate their fabricability and performance. A prototype pump and a 4 x 6 converter need to be built and tested in a liquid metal test loop and component lifetime testing is required to complete the space subsystems development. The all-titanium heat

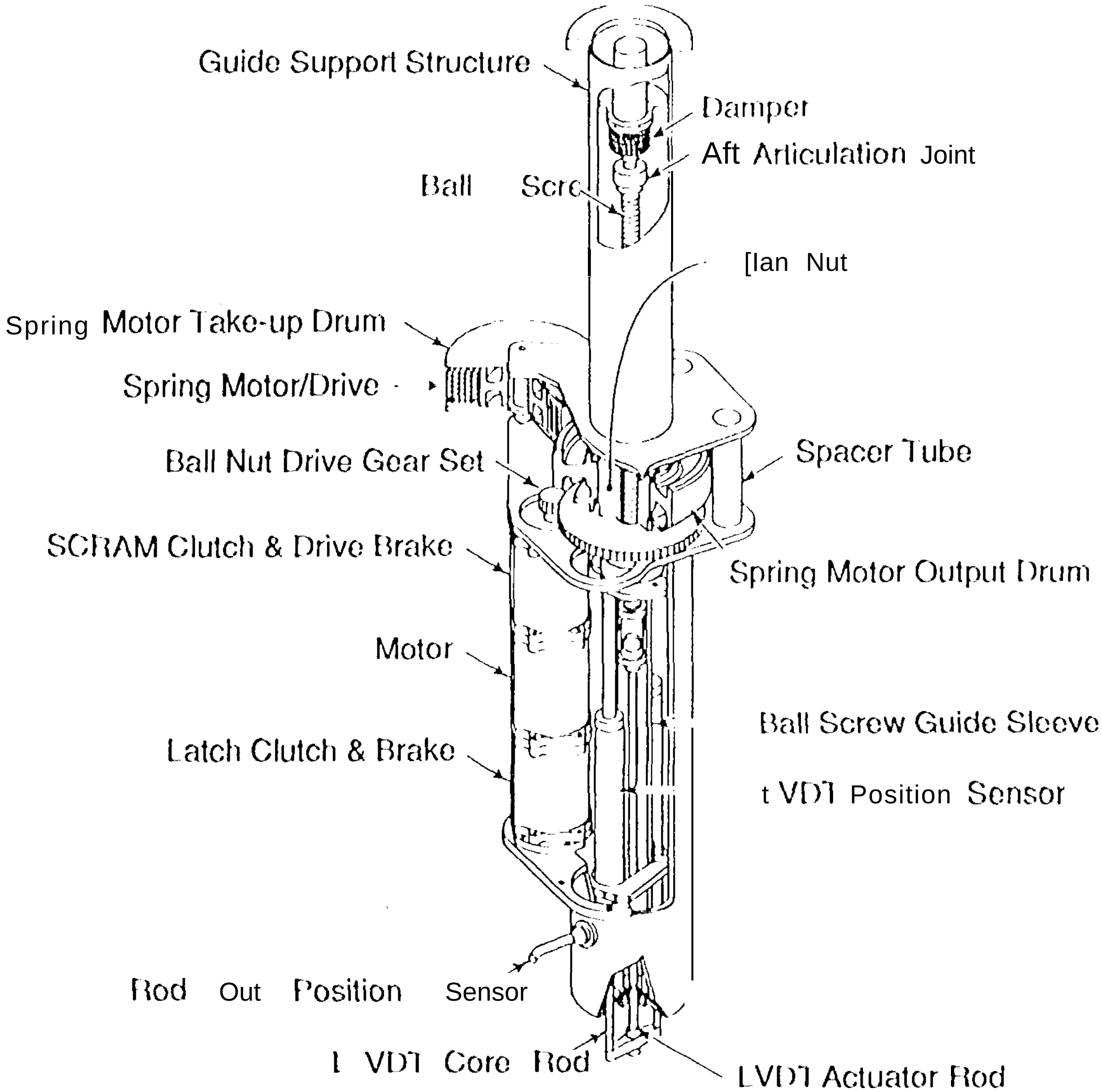


FIGURE 6. 20-kWe SRPS Actuator Subassembly.

pipe radiator for the near-term system is developed. The niobium, carbon-carbon heat pipe technology is nearly developed for the intermediate system. The titanium heat pipe with carbon-carbon armor needs to be developed for the mature system.

Converter Status

The SP-100 converter subsystem consists of 2.54 cm x 2.54 cm by 1.? cm thick conductively coupled thermoelectric cells, arranged in thermoelectric converter assemblies (TCAs) and power conversion assemblies (PCAs). Each TCA as shown in Figure 7 is a sandwich consisting of a thin rectangular hot heat exchanger bonded to the faces of two 4 x 6 arrays of cells, and two cold heat exchangers bonded to the cold faces of each 4 x 6 array. Each PCA as shown in Figure 8 will produce 3.4 kWe and consists of eight TCAs whose hot inlet and outlet headers are connected by piping to the reactor while the cold inlet and outlet headers are connected by piping to the radiator.

The development of a conductively coupled compact thermoelectric cell to reduce system mass was a major technical challenge that has been resolved. To prevent the stresses due to differential thermal expansion of the hot and cold heat exchangers and due to the thermal gradient across the thermoelectric module from damaging the thermoelectric

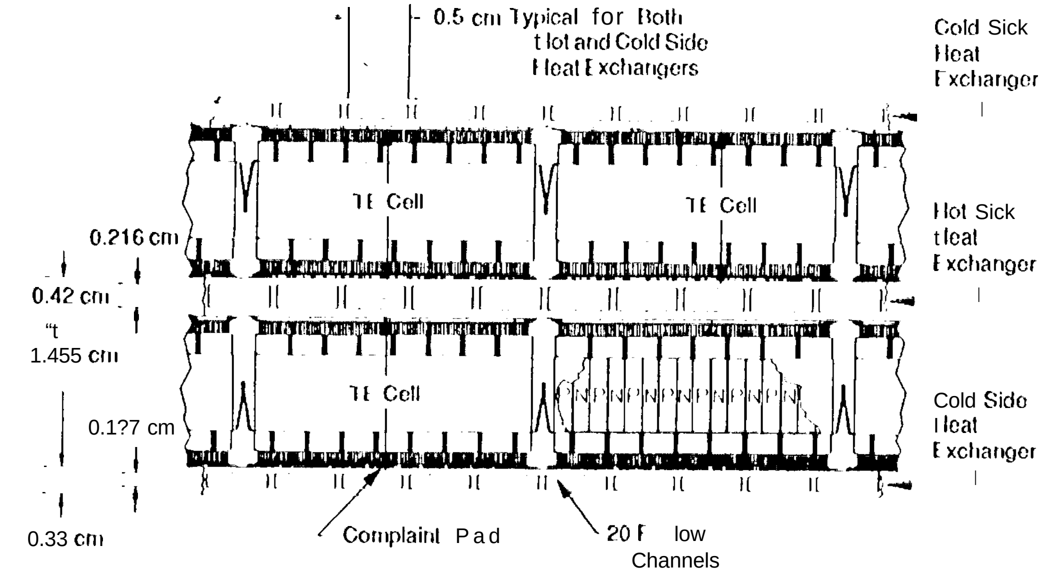


FIGURE 7. Thermoelectric Converter Assembly Cross-Section.

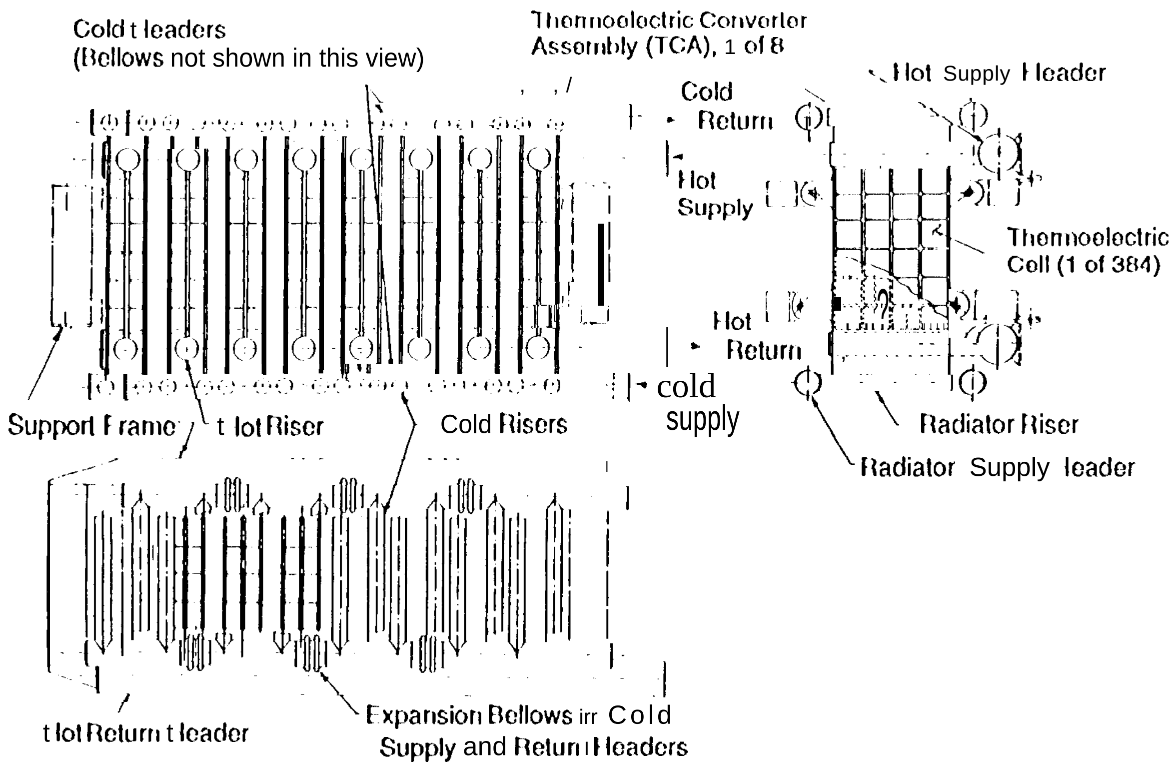


FIGURE 8. 1 of 6 Power Converter Assemblies for the 20-kWe SPS.

materials, the SP-100 design depends on hot and cold compliant fiber pads bonded to each cell. These pads were designed and developed to accommodate thermal strains during cell fabrication, during subsequent thermal cycling, and during normal operations of the TCAs and PCAs. These compliant pads are now developed and their effectiveness in accommodating individual cell thermal stresses has been demonstrated. Their effectiveness in accommodating TCA and PCA stresses has been predicted and needs to be validated in an operating converter.

To date, three prototypic thermoelectric cells have been performance tested. The first type approval (TA) cell, which would be used in the near-term system, operated at prototypic system conditions for 3400 hours as predicted. At this time the internal electrical resistance began to increase more than predicted. At 4100 hours the resistance was three times what it was predicted to be and the TA cell was shutdown and removed for post-test evaluation. The second cell is operating at prototypic conditions for over 5,000 hours with a slightly greater increase in electrical resistance after about 2500 hours than predicted. The third cell operated at prototypic conditions as predicted for about 500 hours and the electrical resistance began increasing more rapidly than predicted. This third cell was shutdown and removed at 2300 hours for post-test evaluation when the electrical resistance was about three times what it was predicted to be. Both the first cell and the third cell were found to be debonded at one of the graphite-to-SiGe "N" leg bonds. This SiGe-to-graphite bond is the weakest bond in the cell and is located on the hot side of the thermoelectric cell where the load is the greatest. The three cells survived more than ten thermal cycles from full temperature (1 300 K hot heat exchanger and 800 K cold heat exchanger) to room temperature. All three cells produced 8.9 watts at a 500 K temperature gradient across the cell (hot exchanger to cold heat exchanger), as predicted prior to the increase in internal electrical resistance. The thermal gradients across all three cells were consistent with the predicted performance throughout the test. The prototype TE cell, structure and performance analyses are confirmed. Four TA cells were fabricated for life testing when the program was terminated.

A 4 x 6 array of cells with a hot exchanger on one side and a cold heat exchanger on the other was fabricated and ready for test at the end or September 1993. This 4 X 6 converter has twelve TA cells like the three that were individually tested and twelve simulated, (graphite blocks substituted for the SiGe material) cells. This 24 cell converter was originally to be tested in a lithium component test loop along with TEM pump in FY 94. The 24 cell, 4 x 6 converter is available for testing to demonstrate that the bonding of cells to heat exchanger is acceptable, that the compliant pads are effective in allowing the difference in thermal expansion between the hot and cold heat exchangers, and the electrical performance with multiple cells in series is as designed.

Remaining Converter Tasks

The SiGe-to-graphite bond needs to be improved and several TE cells need to be fabricated and tested to validate cell lifetime. The 4 x 6 converter should tested to validate compliant pad performance as well as the intercell electrode leads. The 24 cell, 4 x 6 converter, fabricated in FY 93, needs to be electrically heated and tested or installed in a liquid lithium test loop and tested. This 4 x 6 converter, with 12 TA cells and 12 simulated cells, should be tested at prototypic thermal vacuum conditions to validate the compliant pads' effectiveness in limiting the stresses in the TE cells. In parallel, a 48-cell, double-sided 4 x 6 thermoelectric converter assembly (TCA) needs to be fabricated using the improved SiGe-to-graphite bonded TE cells. The 48-cell TCA should then be installed and tested in a liquid lithium pump/converter test loop. This test will validate the 4 x 6 TCA performance, and continued testing is required to validate the compliant pad and intercell electrode lead lifetime. The power conversion assembly (PCA), which consists of eight TCAs, needs to be fabricated with at least one real TCA and the rest simulated. This PCA needs to be integrated and tested in an end-to-end system test to validate the conversion subsystem.

TE cell development needs to be continued to demonstrate TE cells performance and lifetime using improved silicon germanium with a Z of 0.72 x $10^{-3}K^{-1}$. At least four improved cells need to be placed on life test. Further improved silicon germanium with a Z of 0.85 x $10^{-3}K^{-1}$ needs to be incorporated into TE cells. To demonstrate the TE cell for the mature system, it is necessary to have at least four cells on life test.

The TE cell components (compliant pads, insulators and electrodes) and bonded joints (SiGe/pyrolitic graphite, graphite/W, W/glass and W/Nb) need to be improved to reduce mass and increase lifetime up to at least ten years. Accelerated life tests need to be conducted on these components and joints to validate ten-year life with margin.

Heat Transport Status

The heat transport subsystem development is complete for near-term systems except for final validation tests of the thermoelectric electromagnetic (TEM) pump and the gas separator/ accumulator (GSA), which are both shown in Figure 9. The TEM pump magnetic design has been experimentally verified. An electromagnetic integration test (EMIT) was completed. The EMIT verified the pump design performance by pumping liquid metal using an external electrical DC power supply. The type approval pump (TAP) cell for the pump is nearly developed, and two were tested in FY 93. A fabrication development pump representing near-term technology was built in 1993. This pump has twenty-two TAP cells, twenty-two simulated (graphite blocks, substituted for the SiGe material) cells, and Nb-1Zr hot and cold ducts. The GSA has been designed and tested with water and air to confirm the design predicted performance.

Remaining Heat Transport Tasks

The TEM pump fabricated in FY 93 with twenty-two real cells and twenty-two simulated cells needs to be installed and tested in a lithium test loop. A TEM pump with forty-four real cells and PWC-11 ducts needs to be fabricated and tested in a lithium test loop. The pump needs to be performance tested under expected flight system environmental conditions and then put on life test under accelerated steady state conditions to complete the pump development. Additional TAP cells need to be fabricated and place in accelerated life tests to validate the cell lifetime.

Static lithium/helium screen tests need to be performed to validate the gas separator screen performance. A GSA needs to be fabricated and tested with lithium-helium in a flowing lithium loop. This same GSA needs to be installed in an end-to-end system test.

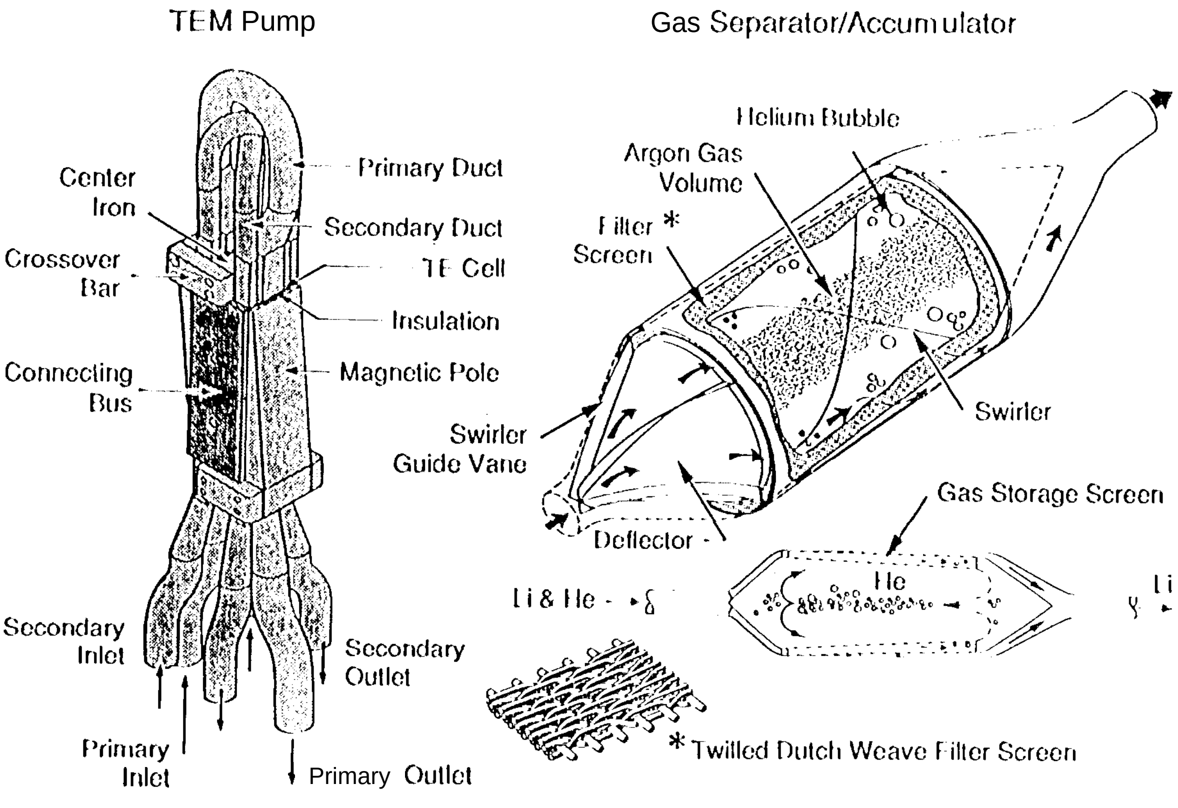


FIGURE 9. TEM Pump and Gas Separator Accumulator.

Heat Rejection Status

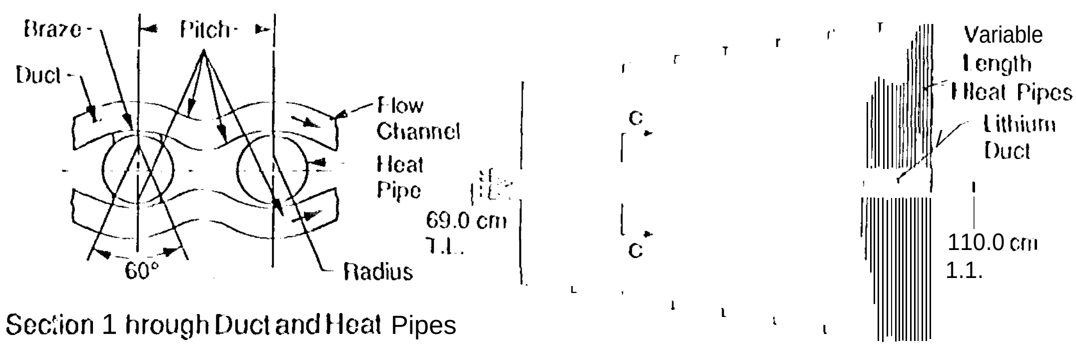
The 20 kWe heat rejection subsystem near-term technology radiator panel is shown in Figure 10. The near-term heat rejection subsystem consists of all titanium ducts, heat pipes, and armor. Six titanium low-cost production potassium heat pipes were fabricated. Two heat pipes were tested for start-up, shut-down, and restart by simulating system predicted conditions. Four of the six were used to demonstrate ten-year lifetimes by accelerated testing. Improved (lower mass) radiator heat pipes are being developed. Three thin walled Nb-1Zr with bonded carbon-carbon (C-C) armored potassium heat pipes were fabricated and one of the three was tested at prototypic temperature.

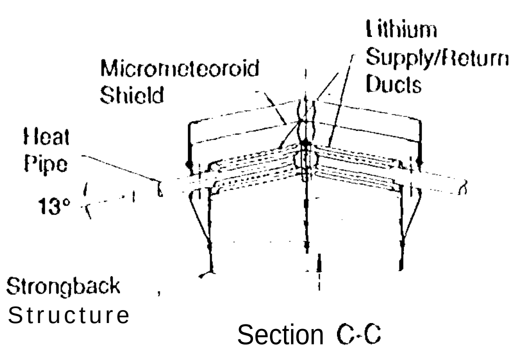
Remaining Heat Rejection Tasks

The improved heat rejection subsystem development started under the NASA-LeRC Advanced Radiator Concepts program needs to be continued and completed. This needs to include evaluation of heat pipes built and tested in FY 93 as well as fabrication and test of additional Nb-1Zr heat pipes with high conductivity carbon-carbon armor and fins. The radiator duct to heat pipe configuration needs to be designed using inputs from the SP-100 20-kWe system design and the results of the Nb-1Zr/C-C heat pipe development. The final validation task is to integrate all the components into a prototypic radiator panel to test and verify the predicted performance in the end-to-end system test. The mature technology requires the development of lower mass heat pipes, such as a 1.3-cm diameter titanium potassium heat pipe with bonded carbon-carbon fins and armor. This technology would also require building and testing a flight radiator panel.

SP-100 Flight System Designs

A generic flight system (GFS) design was completed in May 1988, which met the functional system requirements for a 100-kWe Earth orbital potential military mission. The technology developed by the SP-100 program is based on the GFS system design. The GFS design was updated to meet changing mission requirements and to assure that the technology being developed would satisfy the design changes. A major GFS system update was completed in May 1992





20-kWe System Radiator Parameter	Value
Total heat rejection (kWt)	526
Physical area (m^2)	?9.5
Number of heat pipes	600
Average lithium temperature (K)	815.8
Average condenser surface temperature (K	784.9
Average view factor to space	1.35
Heat pipe inside diameter (cm)	2.54
No. of variable HP lengths	8.0
Evaporator length (cm)	9.2-/

FIGURE 10. 1 of 6 Radiator Panels for the 20-kWe S1<1'S.

to meet changing requirements, with emphasis on civilian missions. The technology being developed was again reviewed with minor changes made to assure that the right technology was being developed. The details used to direct the technology were defined for a 100-kWe system power level and scaled for other system power levels. Conceptual designs were completed from 10 to 300 kWe during the development period to meet specific military and civilian mission requirements defined by the user community. These conceptual design study results also assured that the SP-100 technology being developed was applicable to the power range from 10 to 300 kWe and would satisfy the different user requirements. Marriott and Fujita (1994) described the evolution of the SP-100 system designs from 1986 through 1993.

REMAINING SYSTEM TASKS

An end-to-end integrated system test based on the 20-kWe thermoelectric system design needs to be done to validate all interfaces and components. However, a sufficient test of the system can be accomplished using some partial subsystems such as one TCA, one TEM pump, one control drive actuator, one GSA, and a single radiator segment. Thermal mockups could be used for the remaining components to reduce development costs. The system test would validate that all the components operate as predicted in an overall system configuration.

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References

Truscello, V. C. and Rutger, L. L. (1992) "The SP-100 Power System," Ninth Symposium, Space Nuclear Power Systems Albuquerque, New Mexico, January 1992.

Kelley, J. H. and Yen, C. L. (1993) "Planetary Mission Opportunities with Nuclear Electric Propulsion," *AIAA 92-1560*, AIAA Space Programa and Technology Conference, Huntsville, AL, March 24 ?"/, 1993.

Yen, C. L. (1993) "Nuclear Electric Propulsion for Future NASA Space Science Missions," JPL Publication D-106tW, Jet Propulsion Laboratory, Pasadena, CA, July 1993.

Mondt, J. F. (1992) "SP - 100 Space Reactor Power System for Lunar, Mars and Robotics Exploration," *IAF 92-0563*, 43rd Congress of the International Astronautical Federation, Washington, D.C., September 1992.

Pluta, P. et al. (1993) "SP-1 00 Nuclear Space Power Reactor System Hardware and Testing Progress," 28th Intersociety Energy COnversion Engineering Conference, Atlanta, GA, August 1993.

Mondt, J. F. (1991) "SP - 100 Space Subsystem Development Progress," AIAA 91-3584, AIAA/NASA/OAI Conference of Advanced SEI Technologies, Cleveland, OH, September 4 6, 1991

Marriott, A. J. and Fujita, T. (1 944) "Evolution of SP-100 Systems Designs," Eleventh Symposium, Space Nuclear Power Systems, Albuquerque, NM, January 1994.